Fermi/GBM view of Magnetar Bursts: Bursts, Burst Active Episodes & Burst Induced Changes

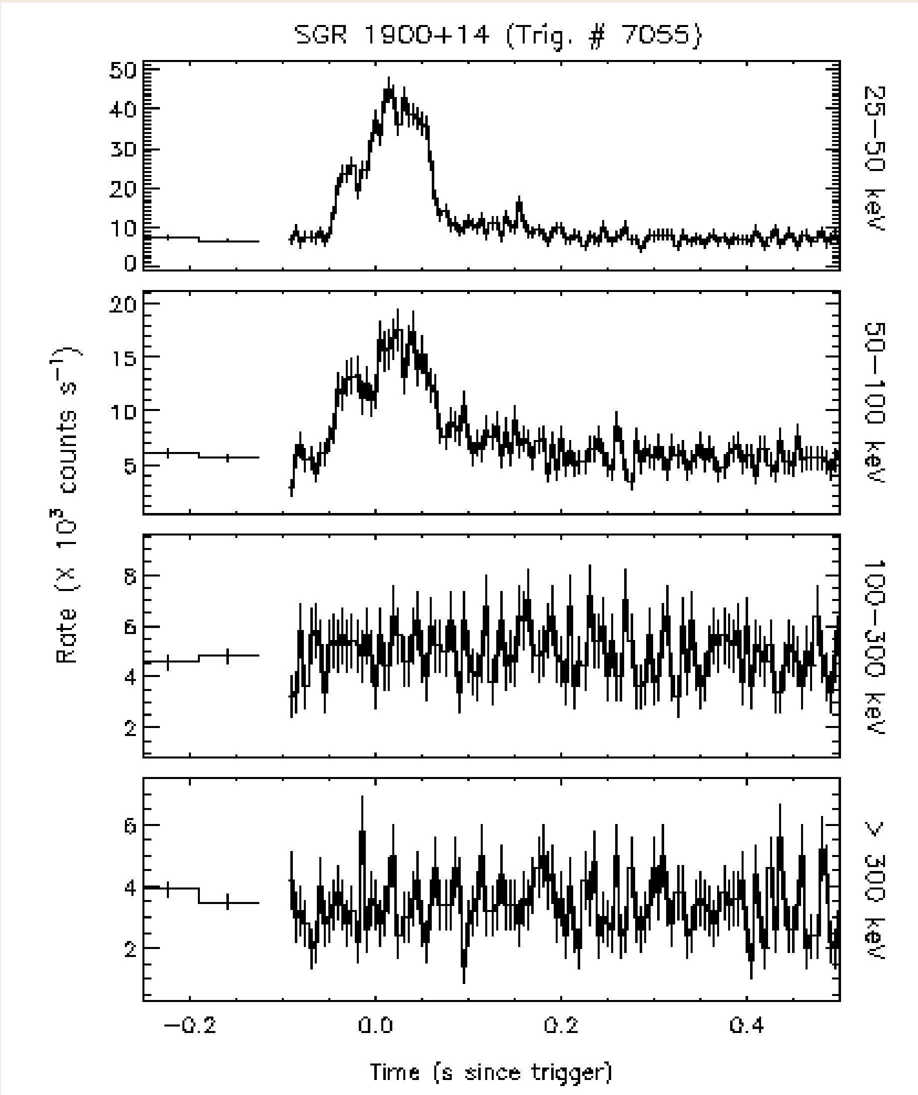
Ersin Göğüş
Sabancı University, Istanbul

in collaboration with the Fermi/GBM team

General Properties of Magnetars

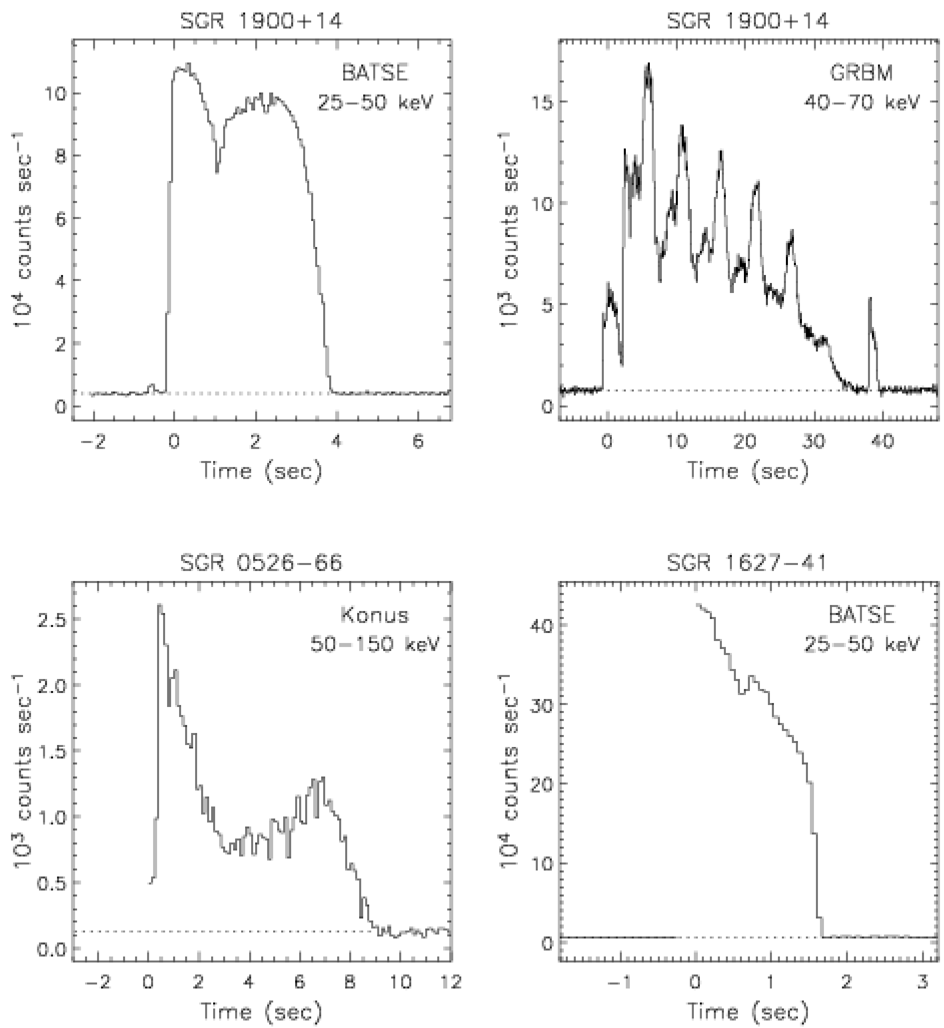
- Slowly rotating systems (P_{spin} ~ 2 – 12 s)
- Rapidly spinning down (dP/dt~ 10^{-13} – 10^{-11} s/s)
- Bright X-ray sources (L ~10^{34}-10^{35} erg/s)
- Transient magnetars (L ~10^{32} erg/s in quiescence)
- Young systems as deduces from their galactic locations
- Unique X-ray spectral properties
- Characterized by <u>bright hard X-ray / soft gamma ray bursts</u>

Typical Magnetar Bursts



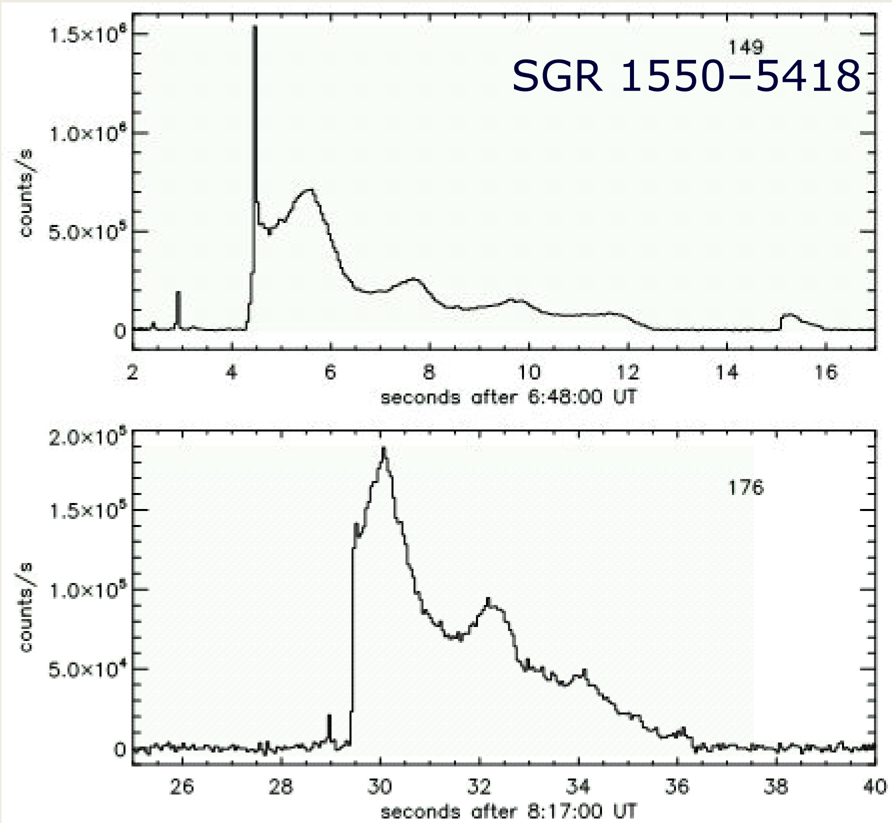
- Brief (~0.1–few s)
- Irregular times between bursts (seconds - years)
- Diverse time profiles
- Intense (~10^{36} – 10^{41} erg/s)
- Distinct from **giant flares** in duration, luminosity and energy spectrum

Intermediate Events

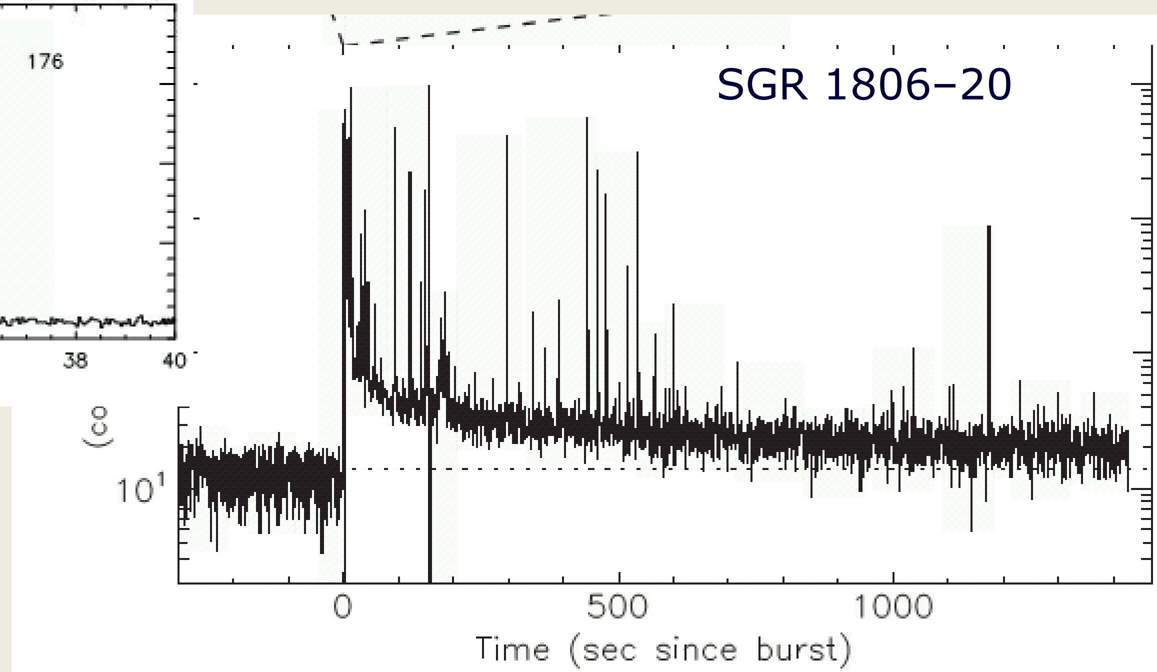


Woods & Thompson 2006

More Intermediate Events

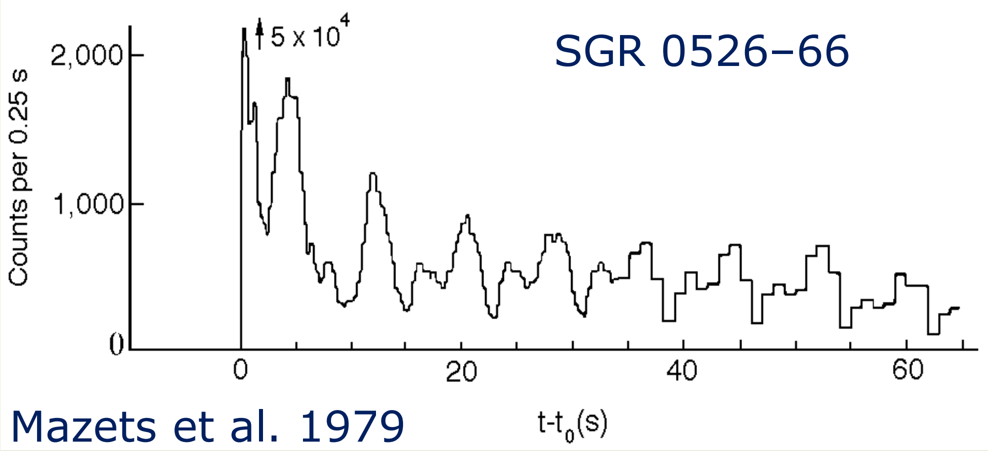


Mereghetti et al. 2010

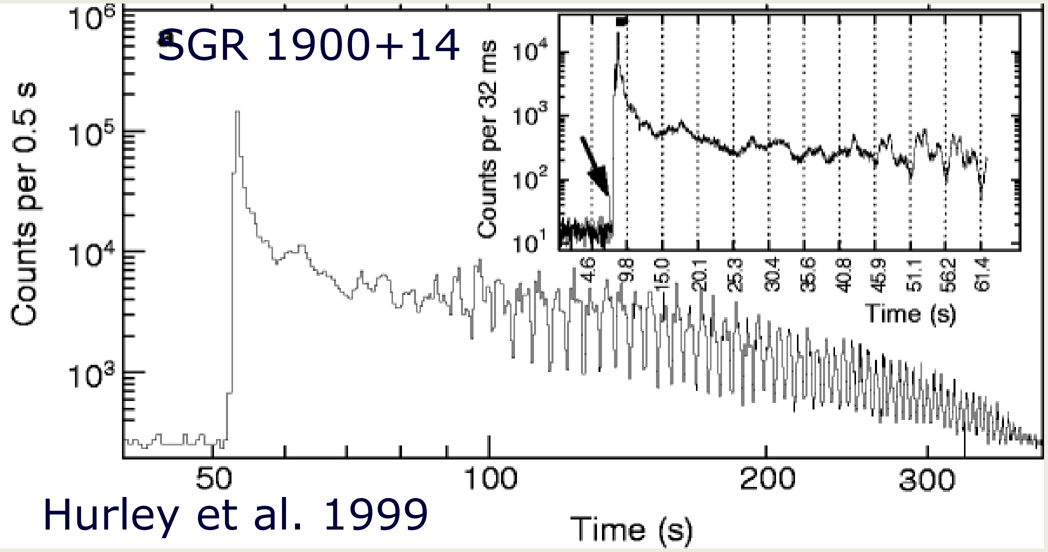


Göğüş et al. 2010

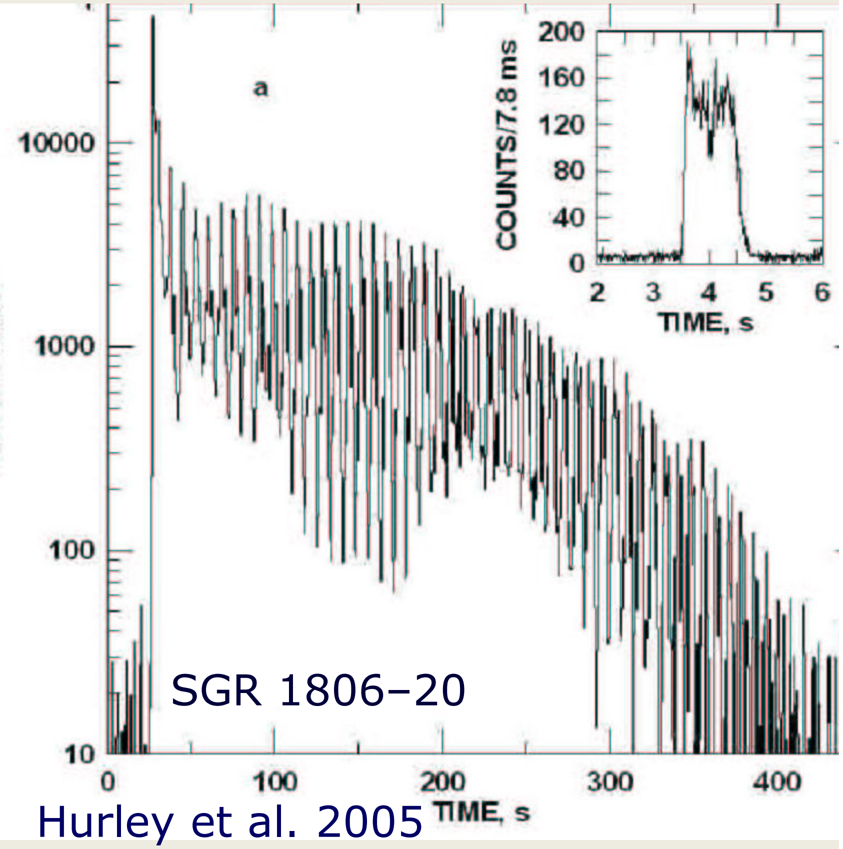
Giant Flares



Mazets et al. 1979



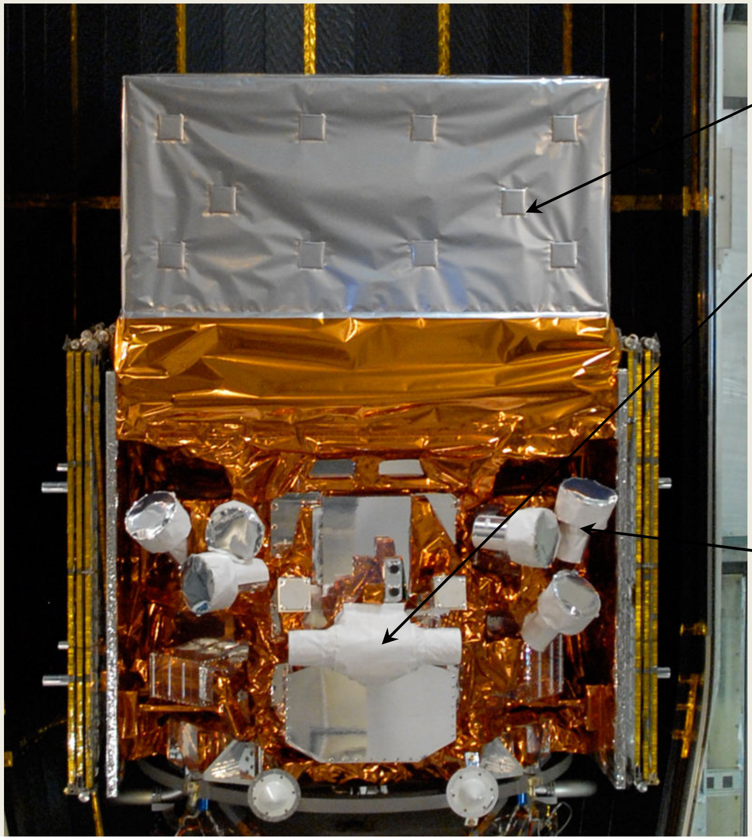
Hurley et al. 1999



Hurley et al. 2005

The Gamma-ray Burst Monitor

- 4 x 3 NaI Detectors with different orientations.
- 2 x 1 BGO Detector either side of spacecraft.
- View entire sky while maximizing sensitivity to events seen in common with the LAT



The Large Area Telescope (LAT)

GBM BGO detector
200 keV – 40 MeV
126 cm^2, 12.7 cm
Triggering, Spectroscopy
Bridges gap between NaI and LAT.

GBM NaI detector
8 keV – 1000 keV
126 cm^2, 1.27 cm
Triggering, Localization, Spectroscopy.

1. GBM magnetar burst catalog

2. Activity based classification of magnetars

3. Burst induced effects in:

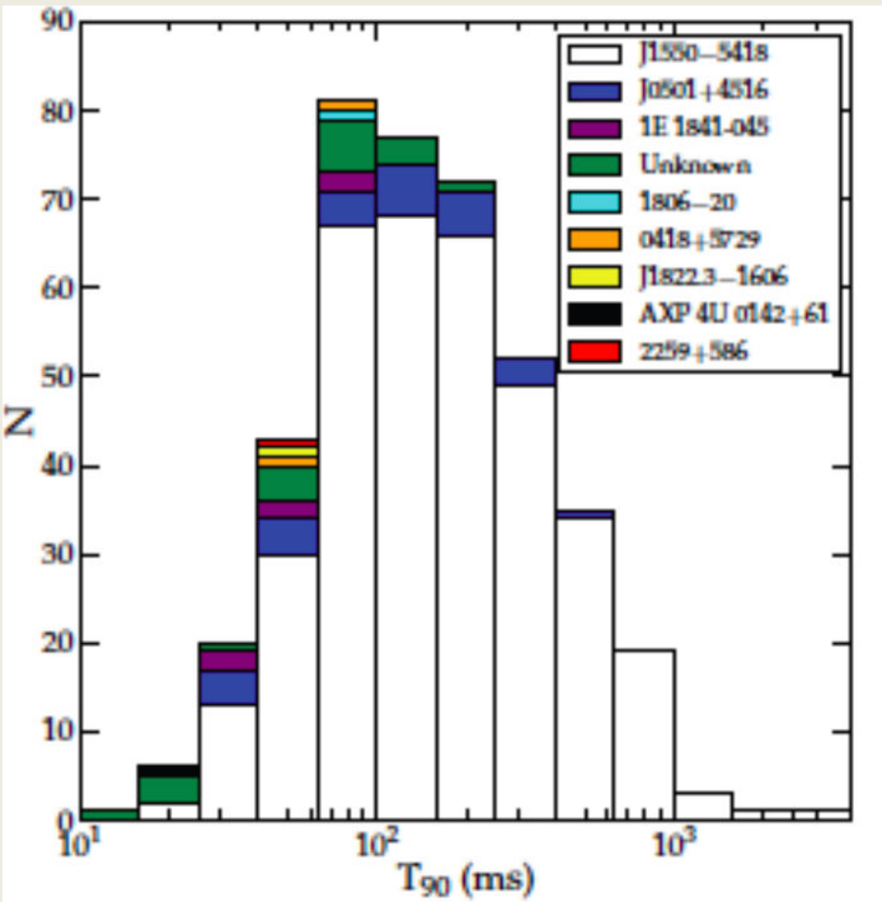
- Persistent soft & hard X-ray emission
- Pulse profile
- Source environment

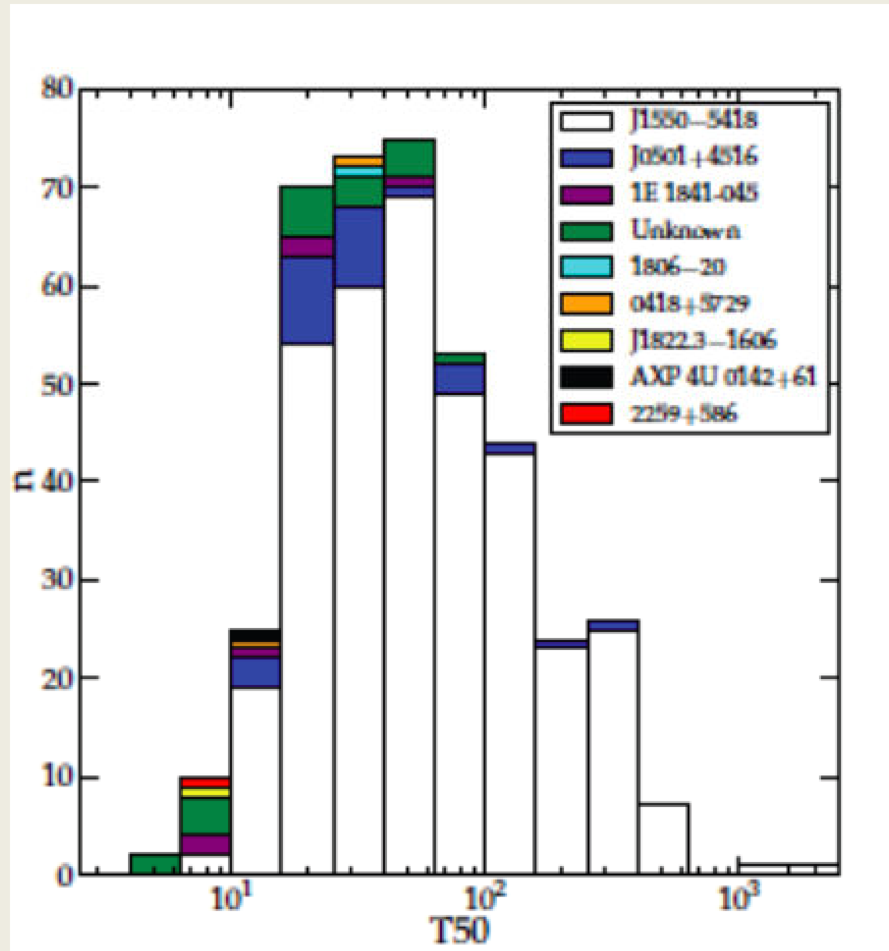
GBM Magnetar Burst Catalog

Collazzi et al. 2015

Magnetar	Active Period	Triggers	Comments
SGR J0501+4516	Aug/Sep 2008	26	**New source** at Perseus arm
SGR J1550-5418	Oct 2008 Jan/Feb 2009 Mar/Apr 2009 June 2013	7 117/331+ 14 1	Known source – first burst active episodes
SGR J0418+5729	June 2009	2	**New source** at Perseus arm
SGR 1806-20	Mar 2010	1	Old source - reactivation
1E 1841-045	Feb 2011 June/July 2011	3 4	Known source – first burst active episodes
SGR 1822-1606 Swift 1834-0846	July 2011 Aug 2011	1 1	**New sources** in galactic center region
4U 0142+61	July 2011	1	Old source - reactivation
1E 2259+586	April 2012	1	Old source - reactivation
Unconfirmed Origin	2008-2013	21	Multiple error boxes include new source 3XMM J185246.6+003317

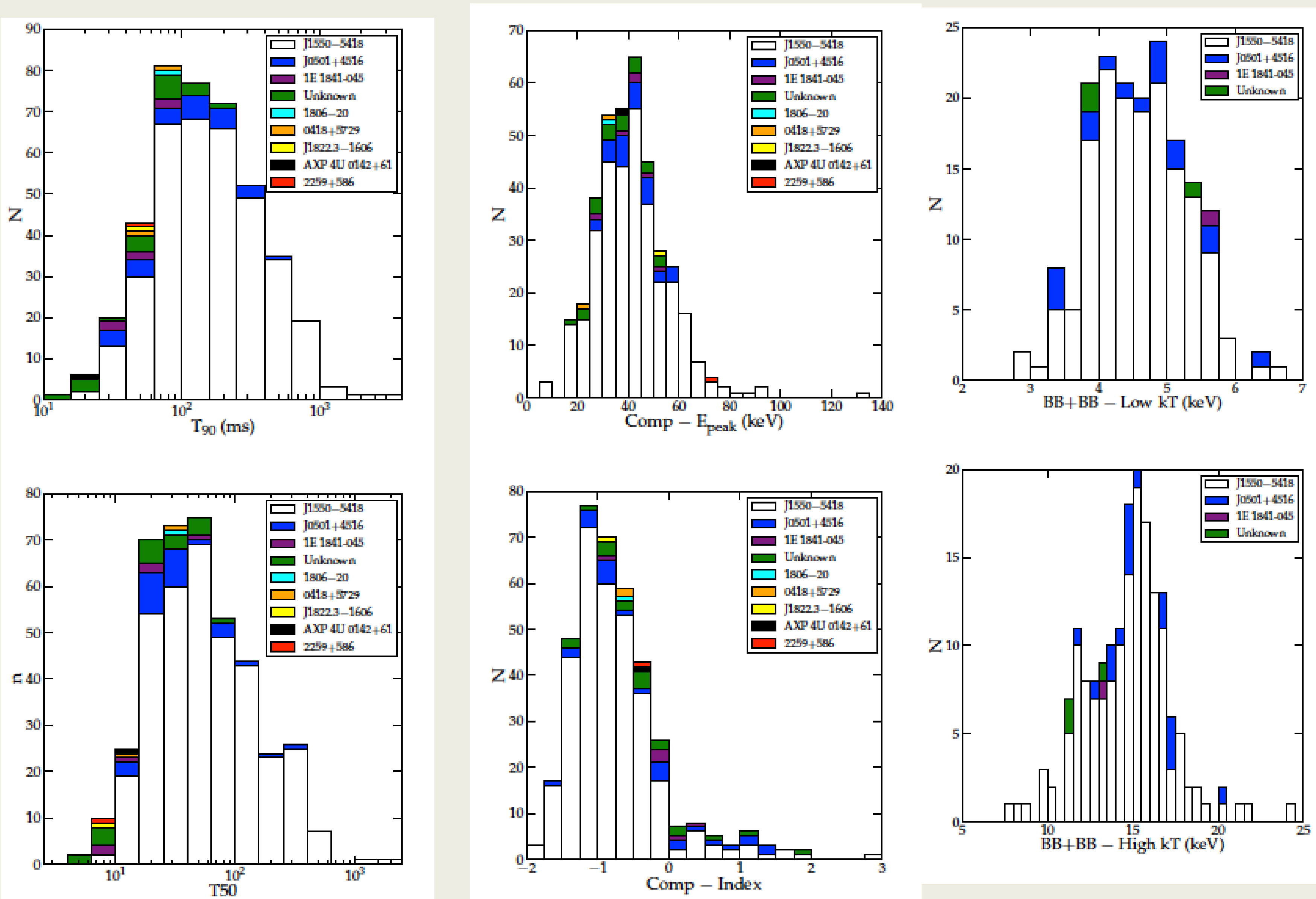
All triggers: temporal properties





Unknown event avg T_{90} = 61 ms (known sources avg ~100 ms)

All triggers: spectral properties



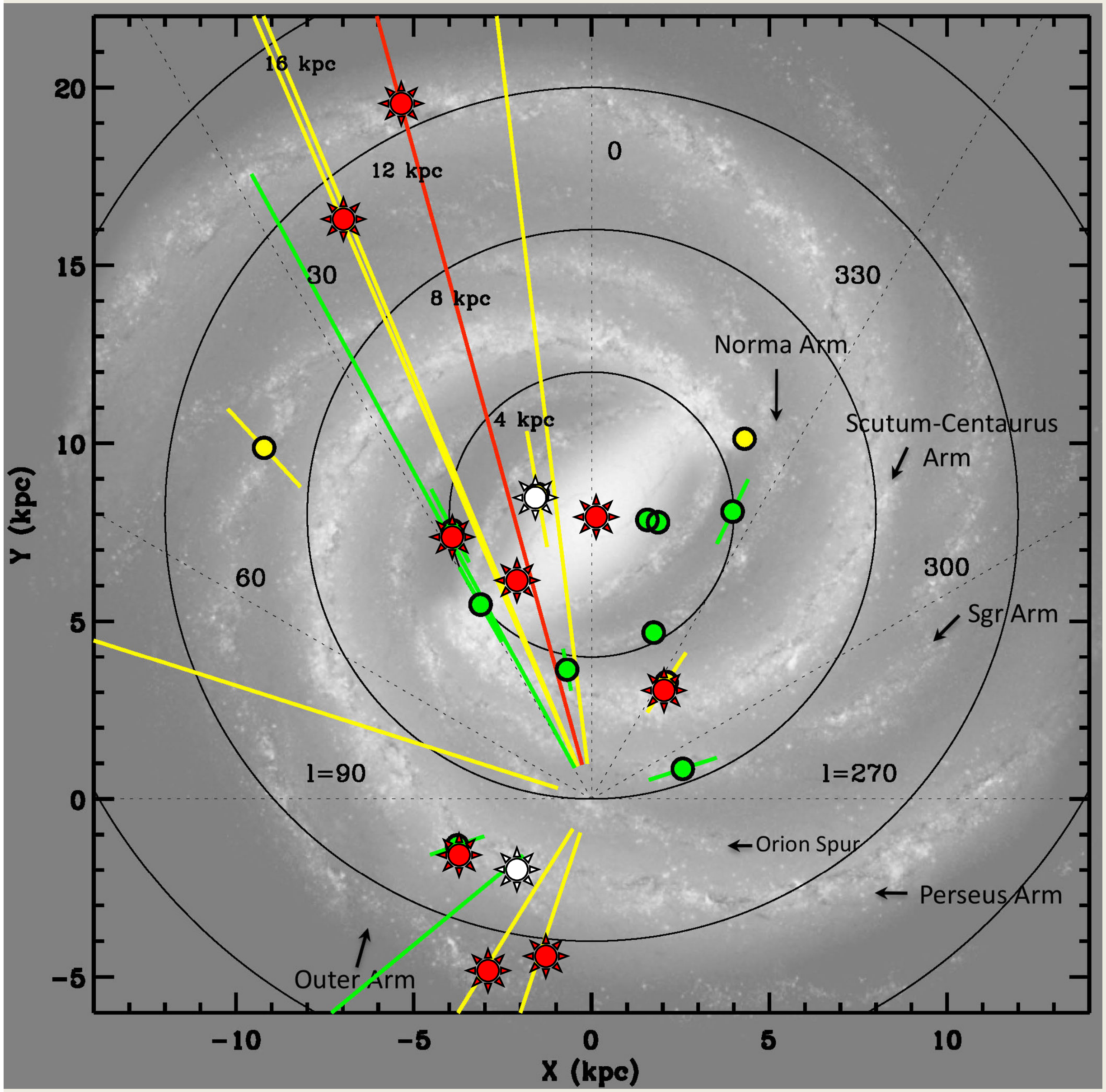
Burst Energetics

SGR 1550-5418
Fluence: $7x10^{-9}$–$1x10^{-5}$ erg/cm^2
E=($2x10^{37}$-$3x10^{40}$) d_5 erg
Flux: $8x10^{-7}$-$2x10^{-4}$ erg/cm^{2}s
L: $5x10^{38}$ -$1x10^{41}{}^{2}$ erg/s
Total Energy Release: $6.6x10^{41}d_5$ erg (8-200 keV)

SGR 1806-20: $3.0x10^{36}$-$4.9x10^{39}$erg
SGR 1900+14: $7x10^{35}$-$2x10^{39}$erg
SGR 1627-41: 10^{38}-10^{41} erg

SGR 0501+4516: $2x10^{37}$-$1x10^{40}$erg
1E 2259+586: $5x10^{34}$-$7x10^{36}$erg

Magnetar Distribution in our Galaxy



NEW: GBM Bursts detected since Fermi launch SYNERGY: Swift-Fermi-RXTE-IPN

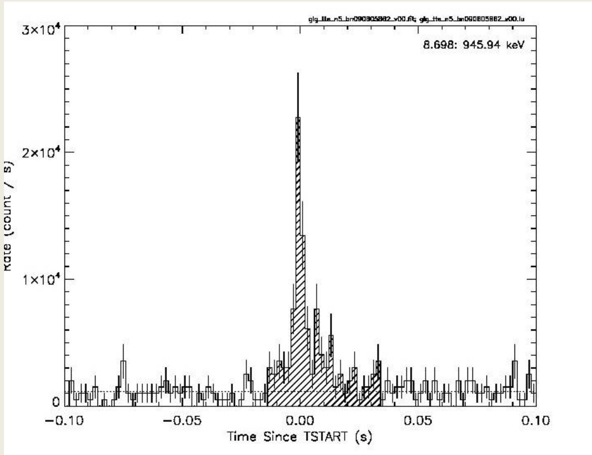
Old source reactivation

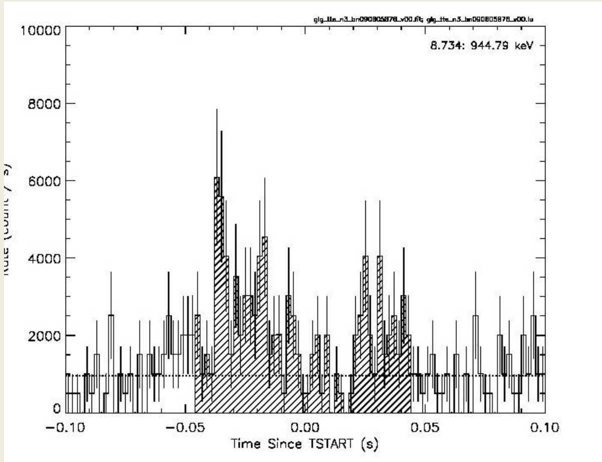
SGRs

AXPs

Kouveliotou et al. 2014

Magnetars with Low Burst Rates



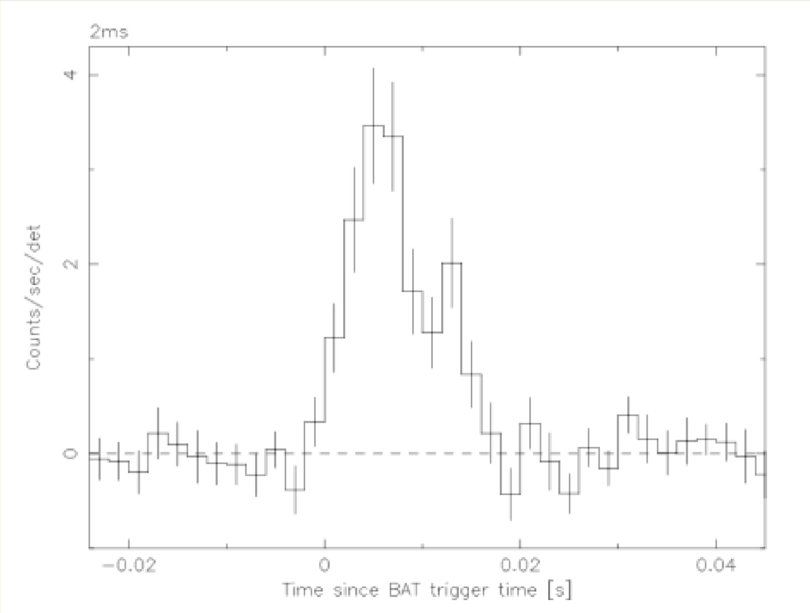


SGR 0418+5729

van der Horst et al. 2010

$B_d = 6 \times 10^{12}$ G

Rea et al. 2010; 2013

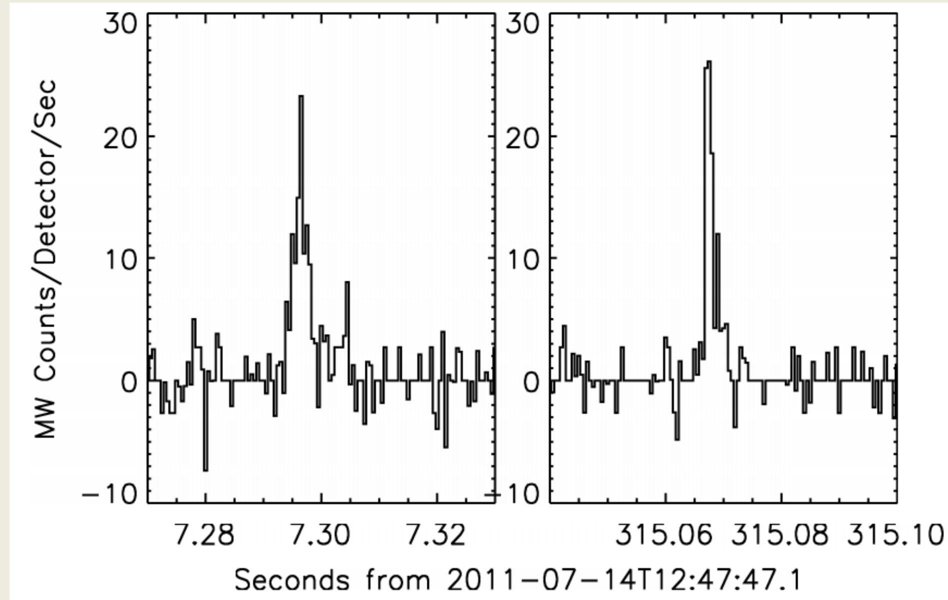


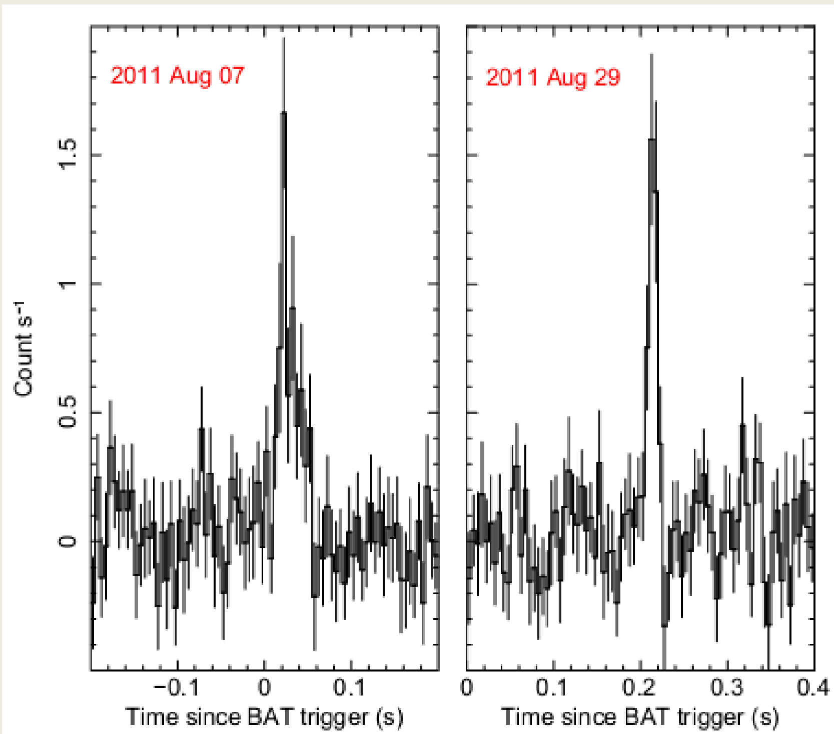
SGR 1833 – 0832

Göğüş et al. 2010

Magnetars with Low Burst Rates

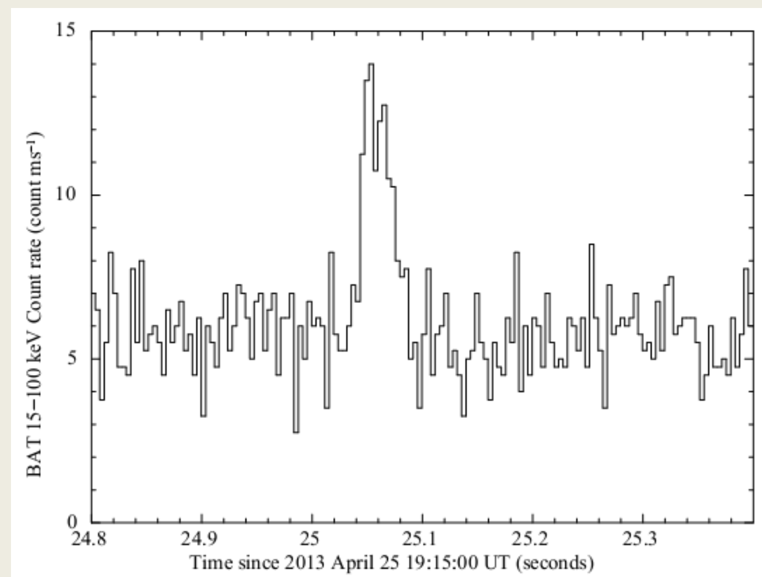
SGR 1822.3–1606 →
$B_d = 2.7 \times 10^{13}$ G
Rea et al. 2012





SGR 1834.9–0846
Esposito et al. 2012

SGR 1745–29 →
Kannea et al. 2013



Magnetars with Low Burst Rates

How can sources with low dipole magnetic fields (e.g., SGR 0418+5729 or SGR 1822.3–1606) generate bursts?

XMM – Newton observations of SGR 0418+5729 on 2009 August 12 for 65 (36) ks gave the answer: Güver, Göğüş, Özel (2011), Tiengo et al. (2013)

T_{90} Duration of Burst Active Episode

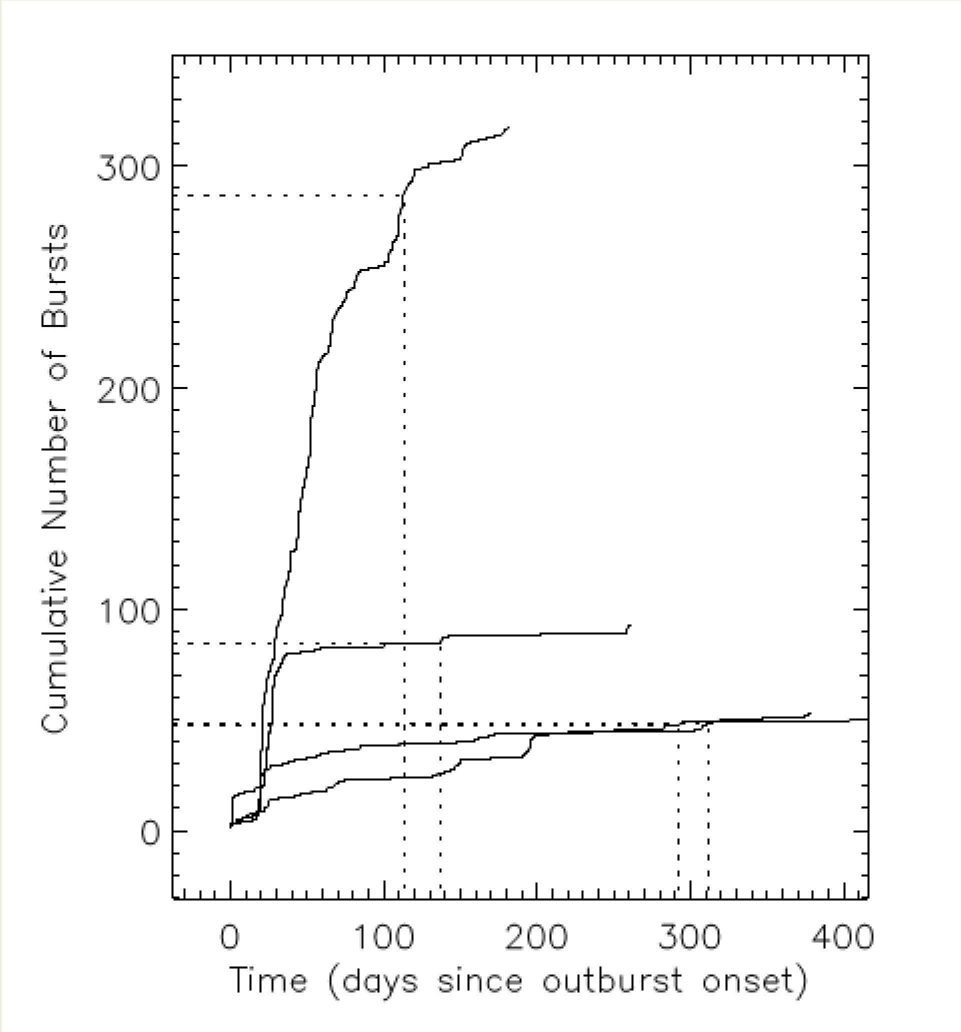
T_{90}: Time since the onset of an outburst during which 90% of all observed bursts are recorded.

Onset of a burst active episode: If at least 5 bursts were observed from the same magnetar in 24 hours.

Source	Outburst
SGR 1550–5418	2009
SGR 1627–41	1998
SGR 0501+4516	2008
SGR 1900+14	1998, 2002
SGR 1806–20	1983, 1996, 1998, 2003/04

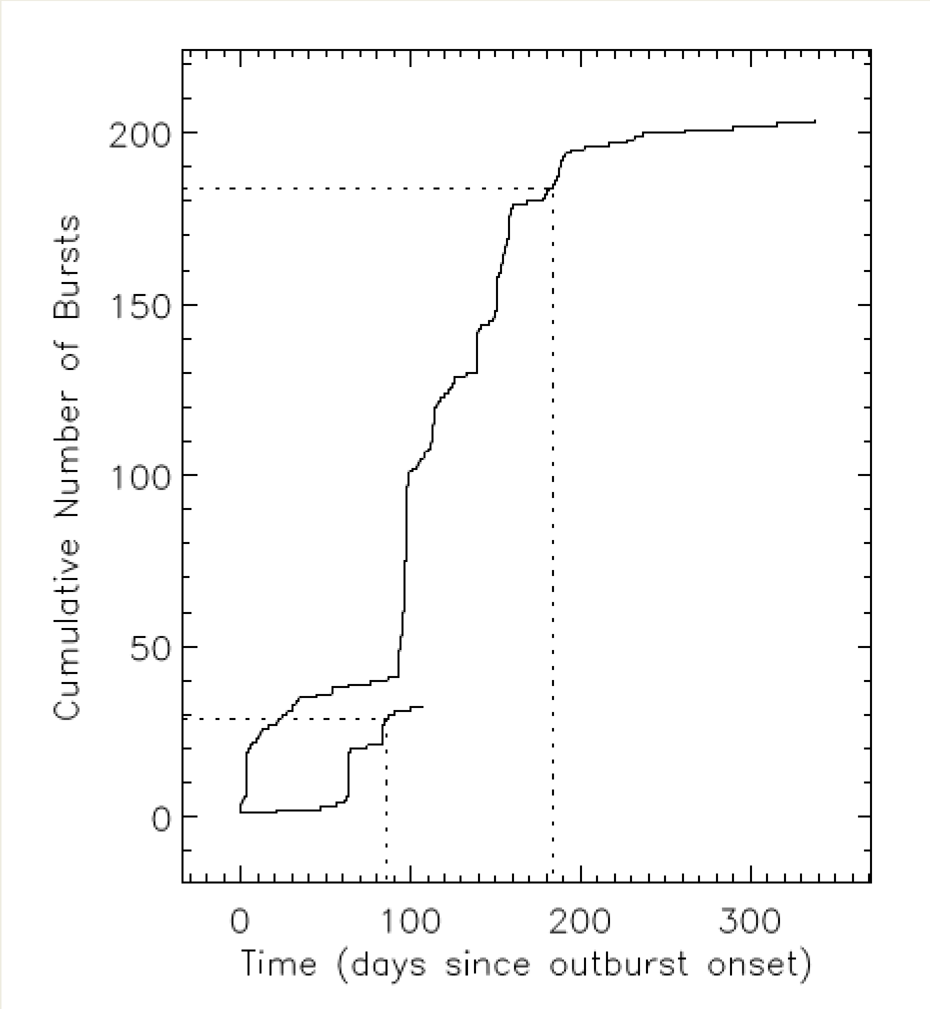
Göğüş 2014

SGR 1806–20: 1983, 1996, 1998, 2003/04



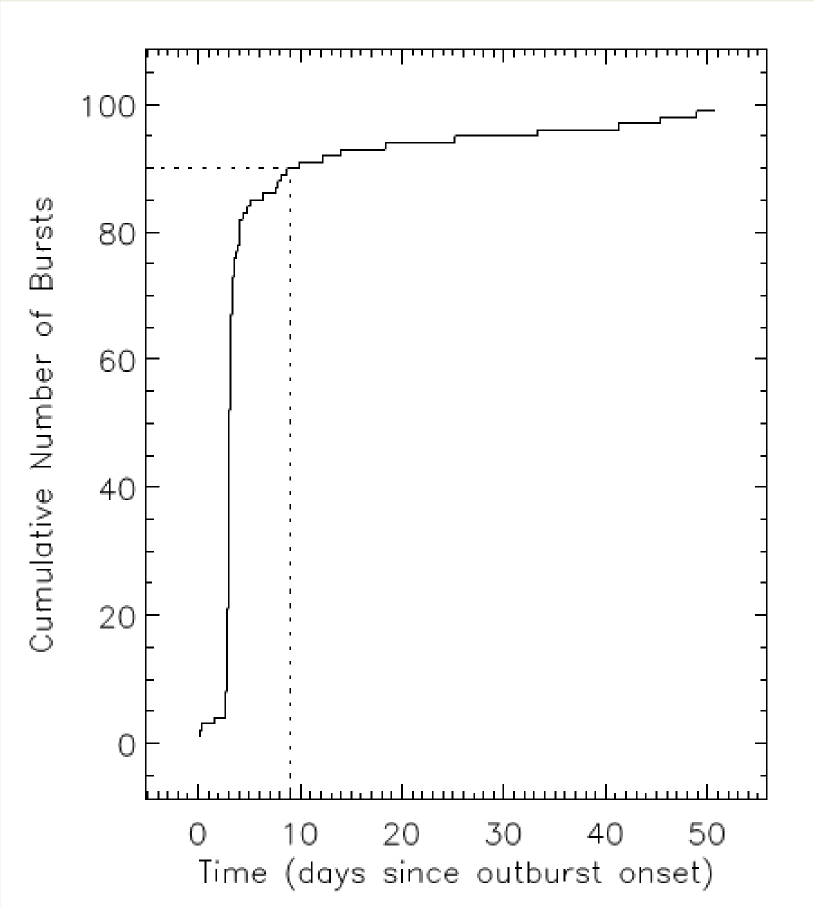
Göğüş 2014

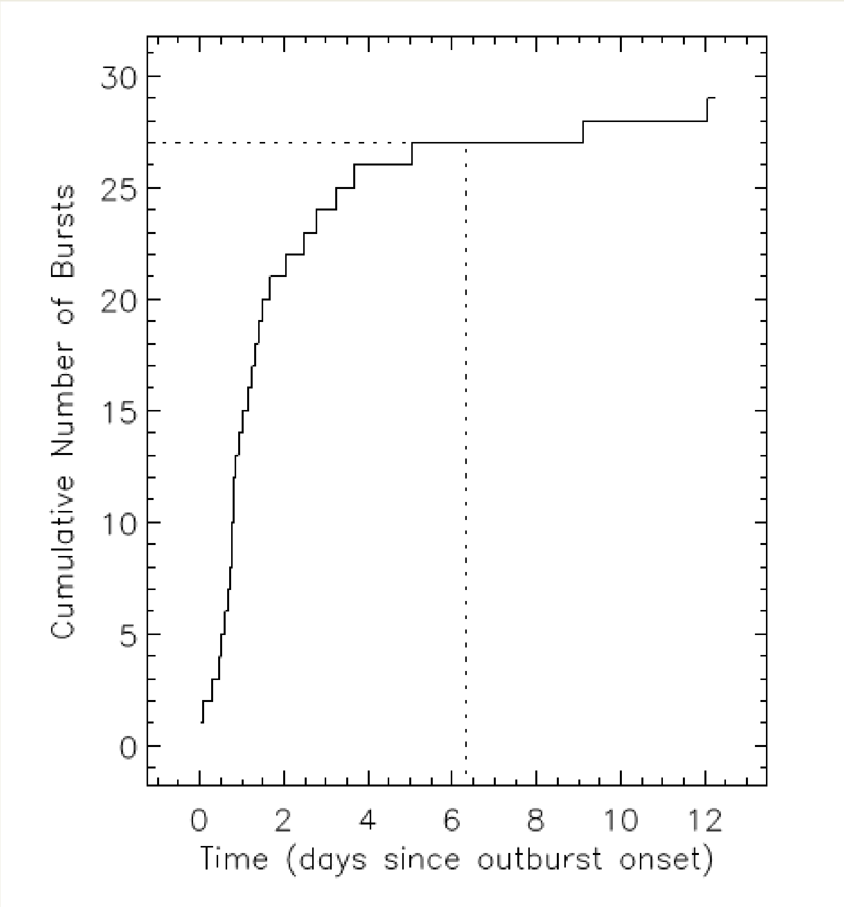
SGR 1900+14: 1998, 2002



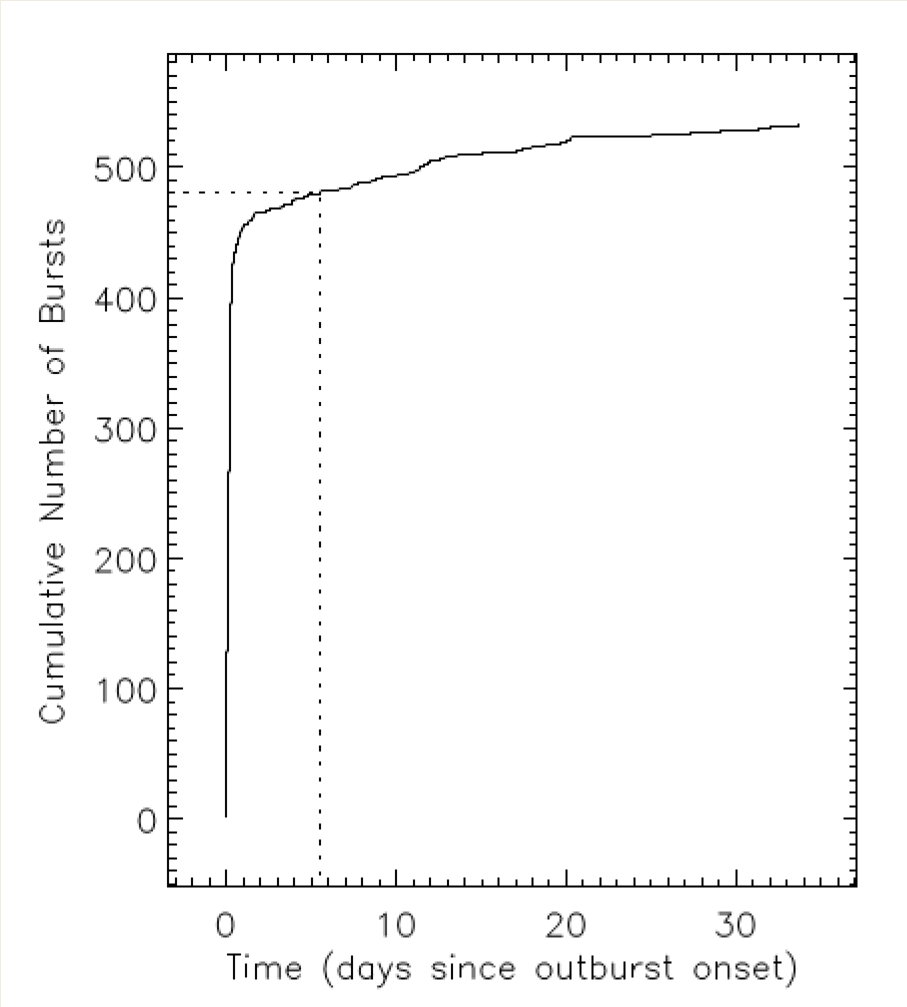
SGR 1627–41 (1998)

SGR 0501+4516 (2008)





SGR 1550+5418 (2009)



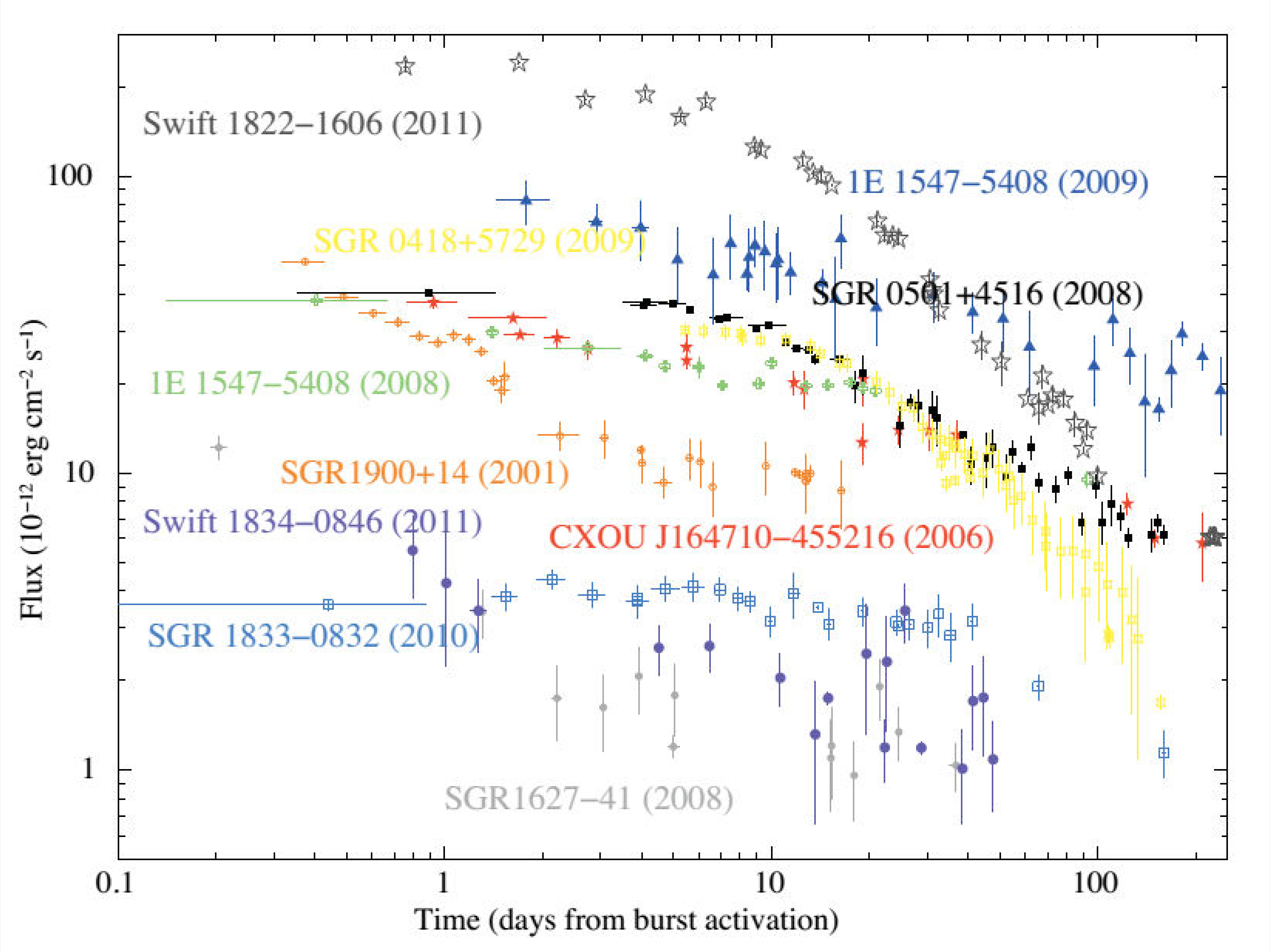
T_{90} of Burst Active Episode

Source	$T_{90-BurstActivity}$
SGR 1550−5418 (2009)	5.6 days
SGR 1627−41 (1998)	9.1 days
SGR 0501+4516 (2008)	6.3 days
SGR 1900+14 (1998)	183 days
SGR 1806−20	112 – 311 days

Burst active episode of a prolific transient lasts less than 10 days.

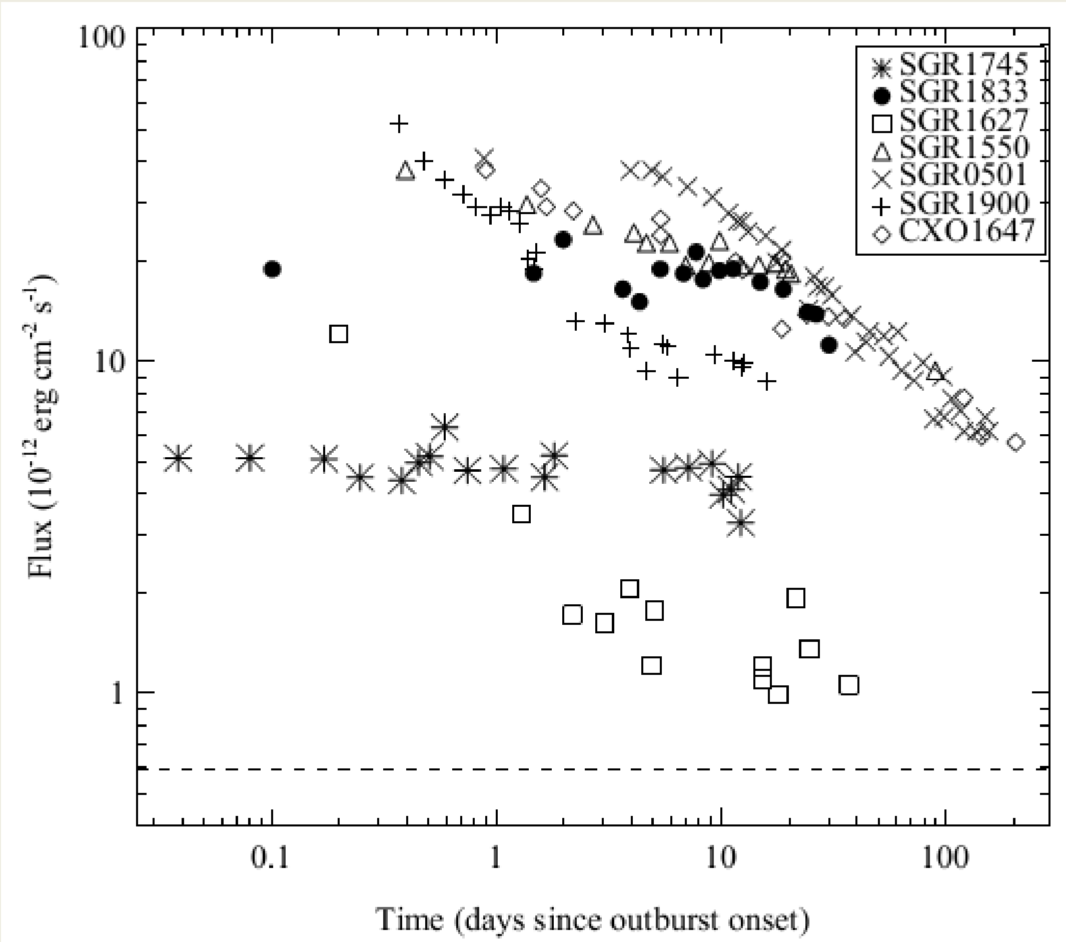
Classification of Magnetars Based on Their Bursting Behavior

Prolific Bursters	Prolific Transients	AXPs with SGR-like Bursts	Transients with Low Burst Rates
SGR 1900 + 14	SGR 1627 - 41	1E 1048-5937 1E 2259+586	SGR 0418 + 5729
SGR 1806 – 20	SGR 1550 - 5418	4U 0142+61 1E 1841-045	SGR 1833 - 0832
SGR 0526 – 66	SGR 0501 + 4516	CXO J164710.2-455216	Swift 1822.3 – 1606
		XTE J1810-197	Swift 1834.9– 0846
		AX J1818.8 - 1559?	SGR 1745 – 29 SGR 1935+2154?


Swift 1822−1606 (2011)
1E 1547−5408 (2009)
SGR 0418+5729 (2009)
SGR 0501+4516 (2008)
1E 1547−5408 (2008)
SGR1900+14 (2001)
Swift 1834−0846 (2011)
CXOU J164710−455216 (2006)
SGR 1833−0832 (2010)
SGR1627−41 (2008)
Flux (10^{-12} erg cm^{-2} s^{-1})
Time (days from burst activation)
0.1
1
10
100
1
10
100

Rea 2014

SGR 1745–29 & SGR 1833–0832 Flux Decay

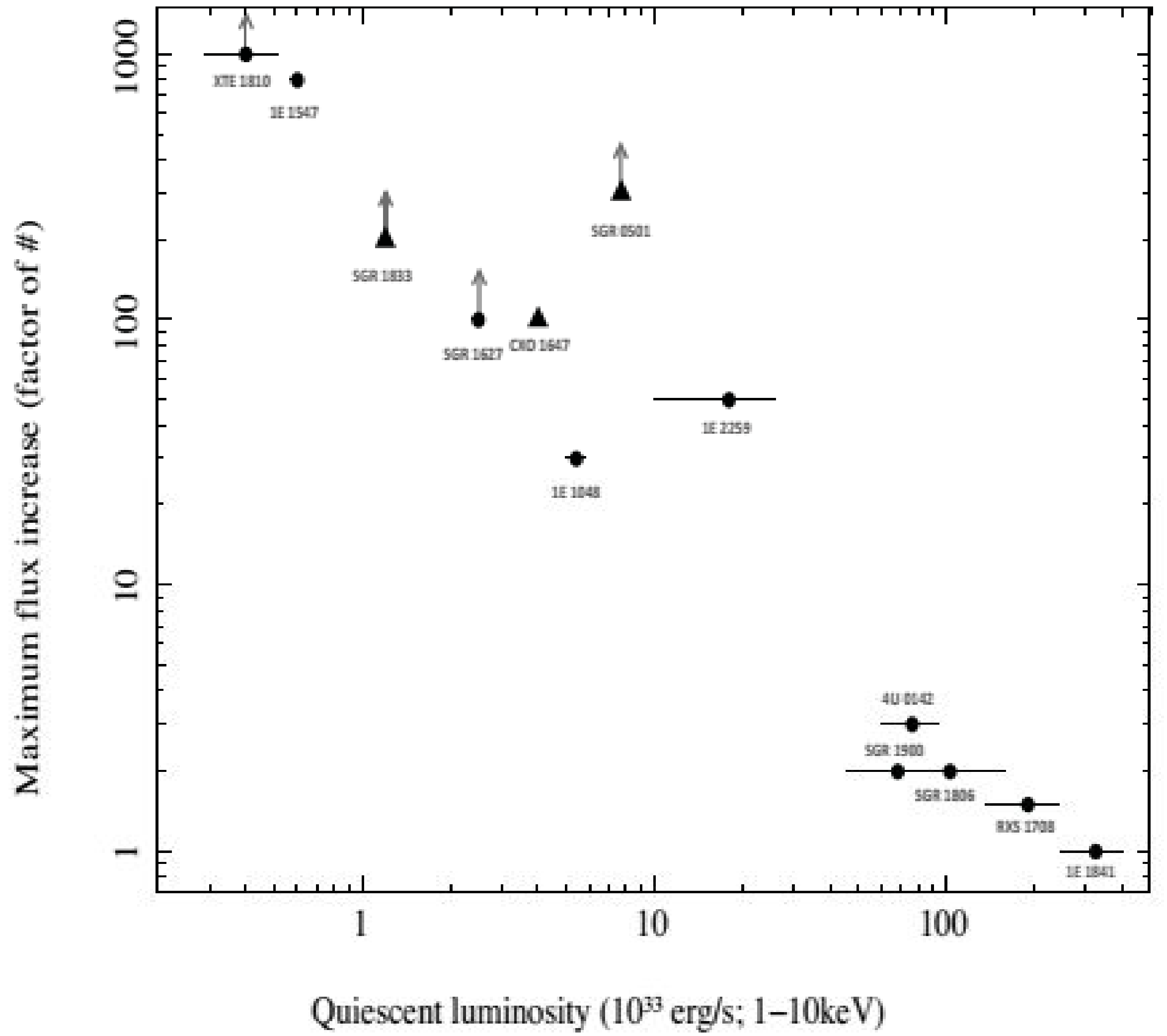


Kannea et al. 2013

X-ray flux of SGR 1745–29 is constant for ~10 days following the onset

Similar flux trend was seen in SGR 1833 – 0832

Continuous heating of the crust by trapped fireball?



Maximum flux increase (factor of #)
1000
100
10
1
XTE 1810
1E 1547
SGR 1833
SGR 0501
SGR 1627
CXO 1647
1E 2259
1E 1048
4U 0142
SGR 1900
SGR 1806
RXS 1708
1E 1841
1
10
100
Quiescent luminosity (10^{33} erg/s; 1–10keV)

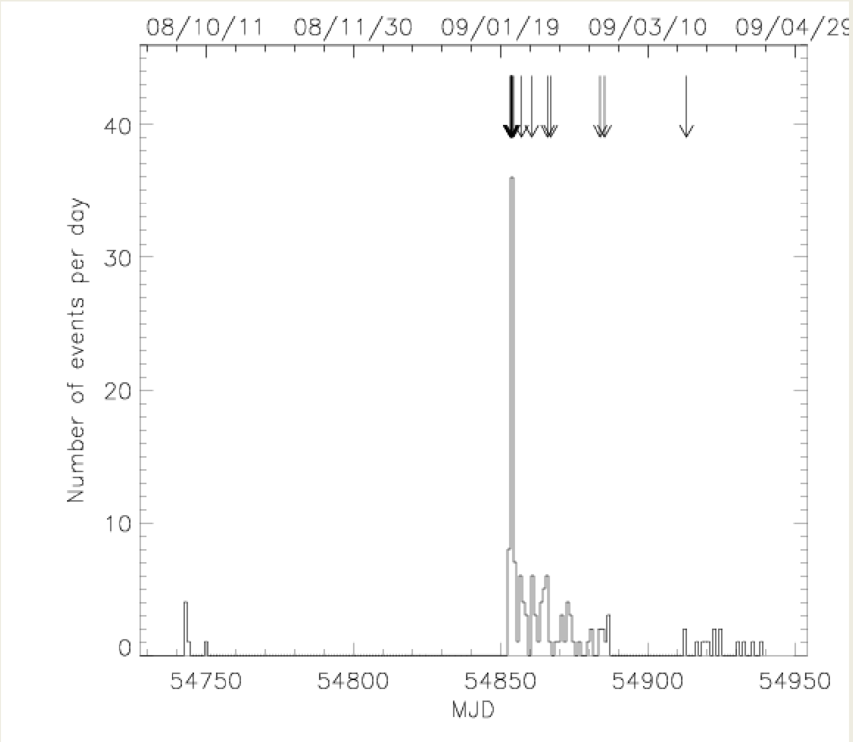
(Rea 2014)

SGR 1550-5418 = 1E 1547.0-5408

ASCA, XMM: "Magnetar Candidate" Gelfand & Gaensler 2007

Radio observation: P = 2.0698 s, $\dot{P}$ = 2.3 x 10^{-11} s / s

B = 2.2 x 10^{14} G → Magnetar   Camilo et al. 2008



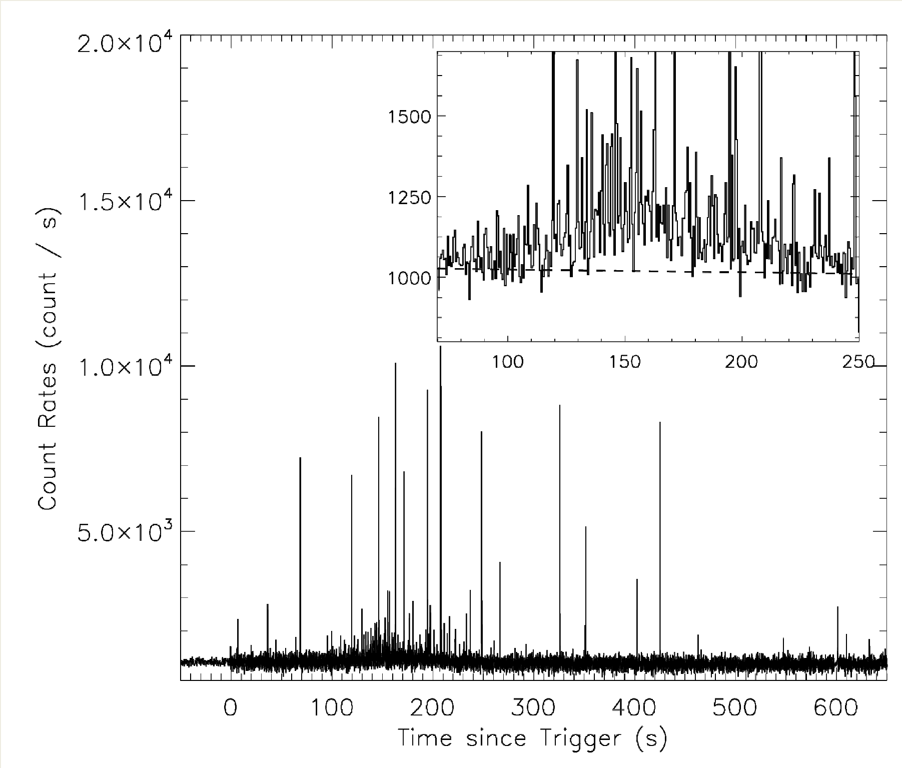
SGR-like bursts:

- Oct 2008 (~1 week)
- Jan-Feb 2009 (~1 month)
- Mar -Apr 2009 (~1 month)

Most intense bursting on **January 22, 2009**

~450 bursts

GBM Trigger 090122037

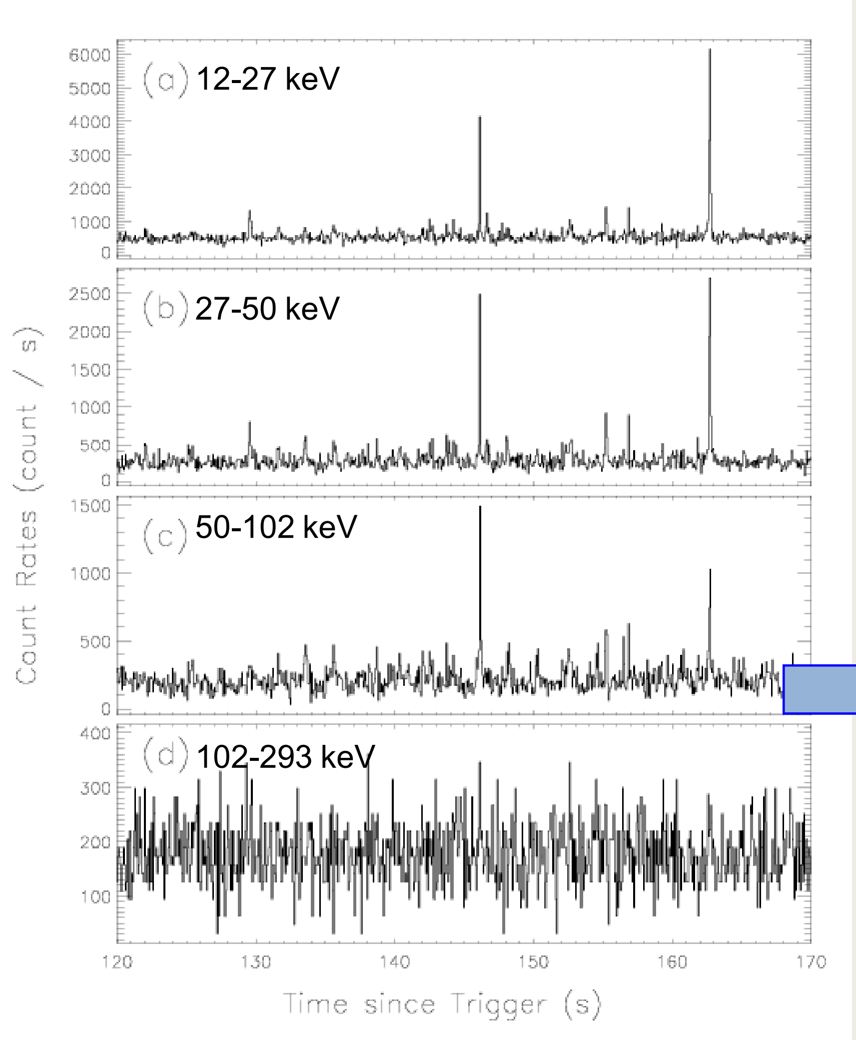


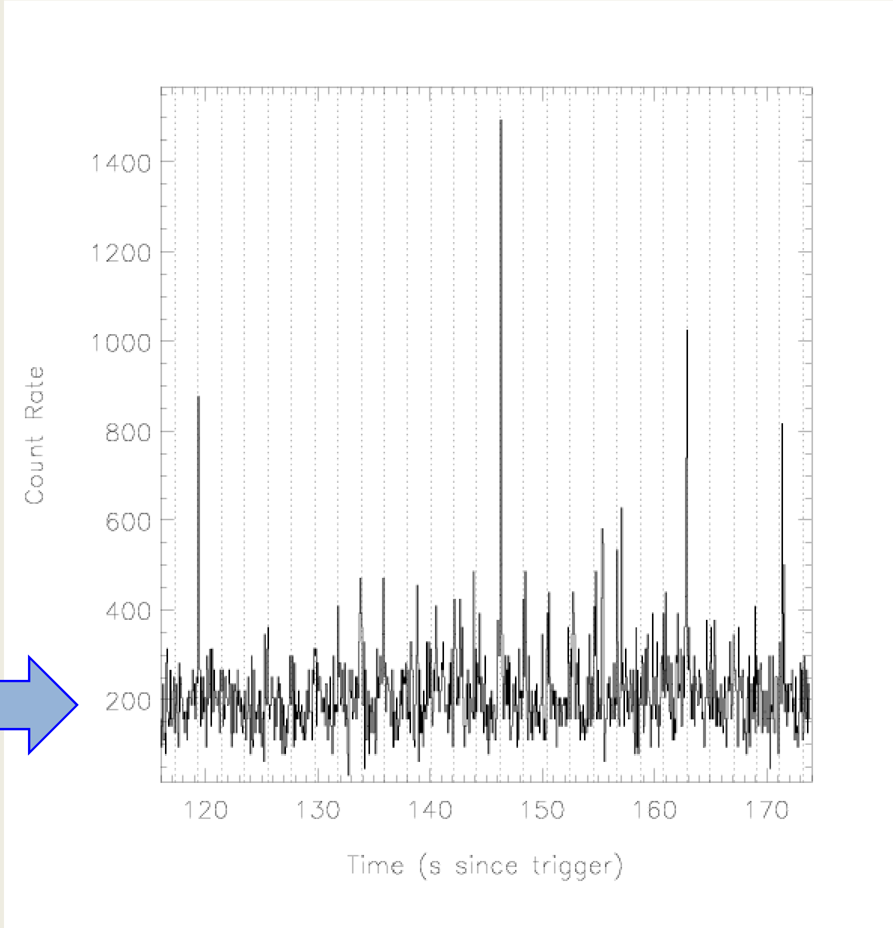
Enhanced Persistent Emission

- Trigger at 00:53:52 UT on January 22, 2009
- 1st of 41 GBM Triggers
- Trigger data for 600 s
- 58 untriggered bursts identified within 600 s

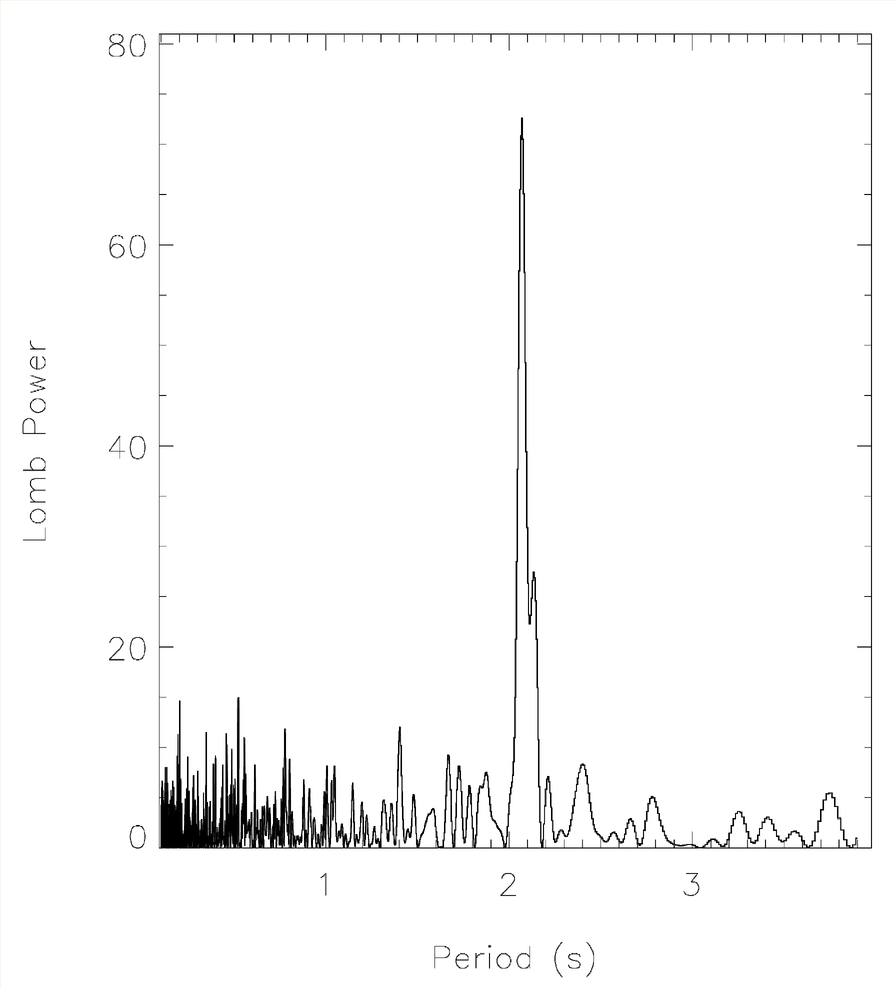
Kaneko et al. 2010

Pulsation Detection





Timing Analysis



Lomb – Scargle test:

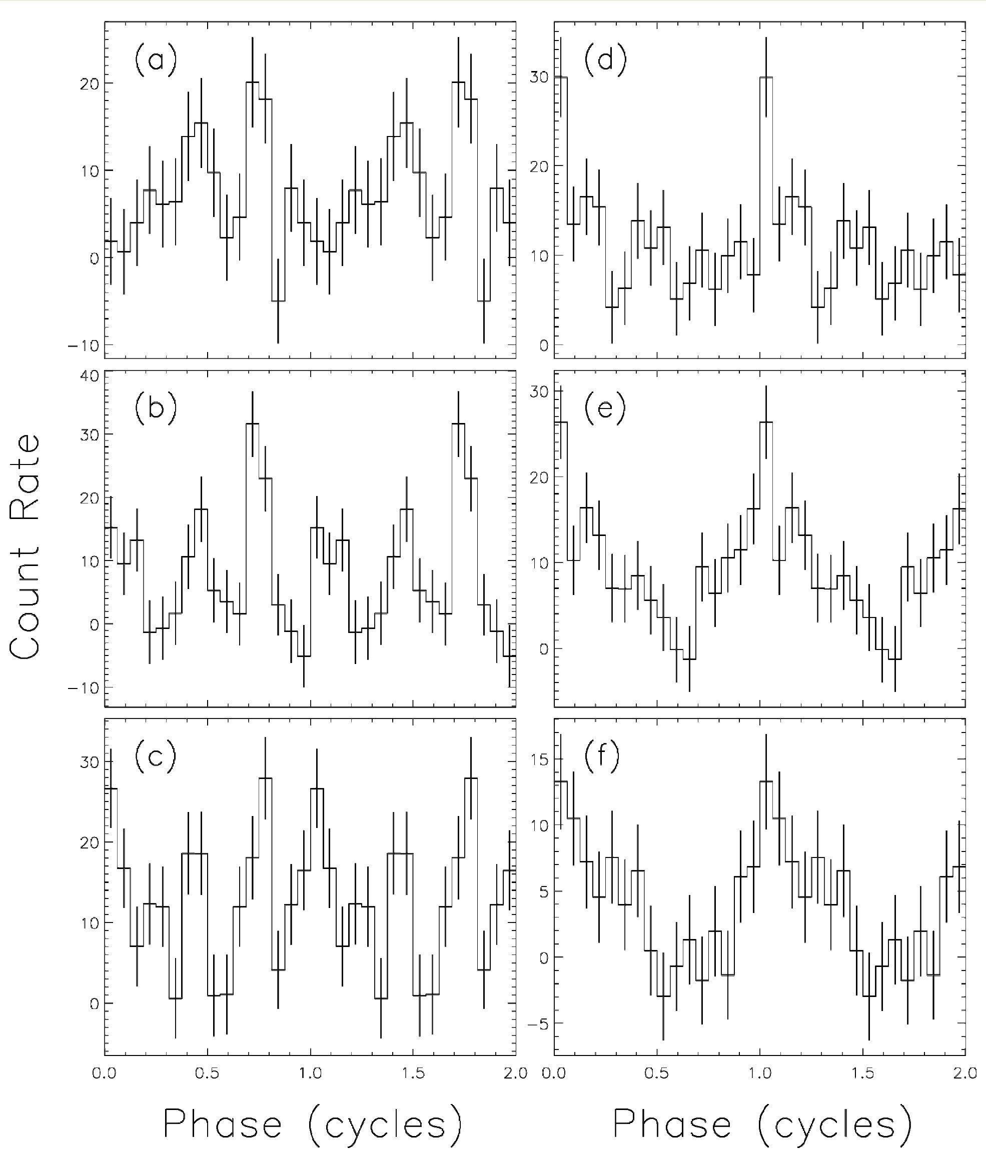
P: 0.1→10 s in 50 – 100 keV

P = 2.0699 ± 0.0024 s

Coherent signal: strongest in T_0 **+ 120 – 210 s**

No other episode of pulsations on this day or the following four days.

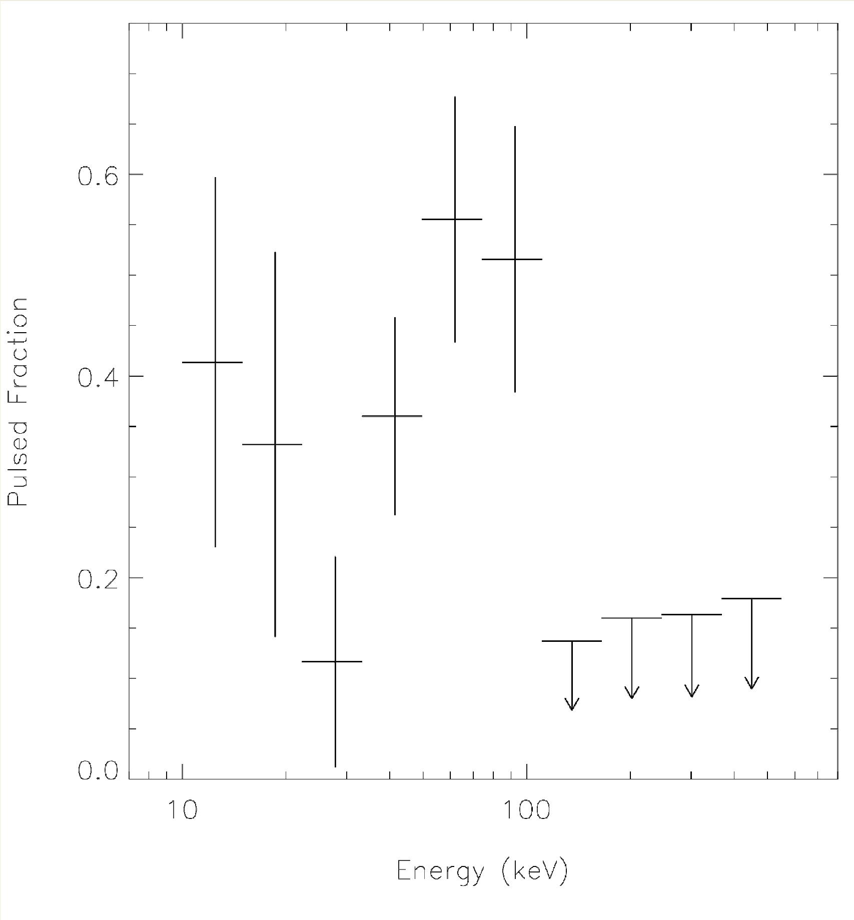
Pulse Profiles



- Double peaked at low E
- Single peak at high E
- No pulsation > 110 keV

(a) 10 – 14 keV
(b) 14 – 22 keV
(c) 22 – 33 keV
(d) 33 – 50 keV
(e) 50 – 74 keV
(f) 74 – 110 keV

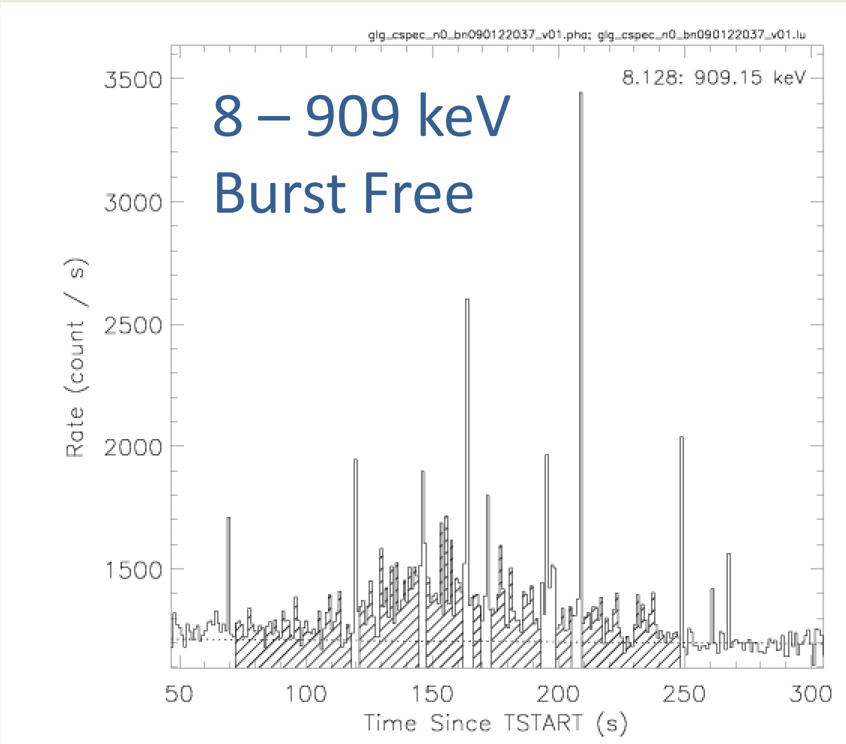
RMS Pulsed Fraction Spectrum

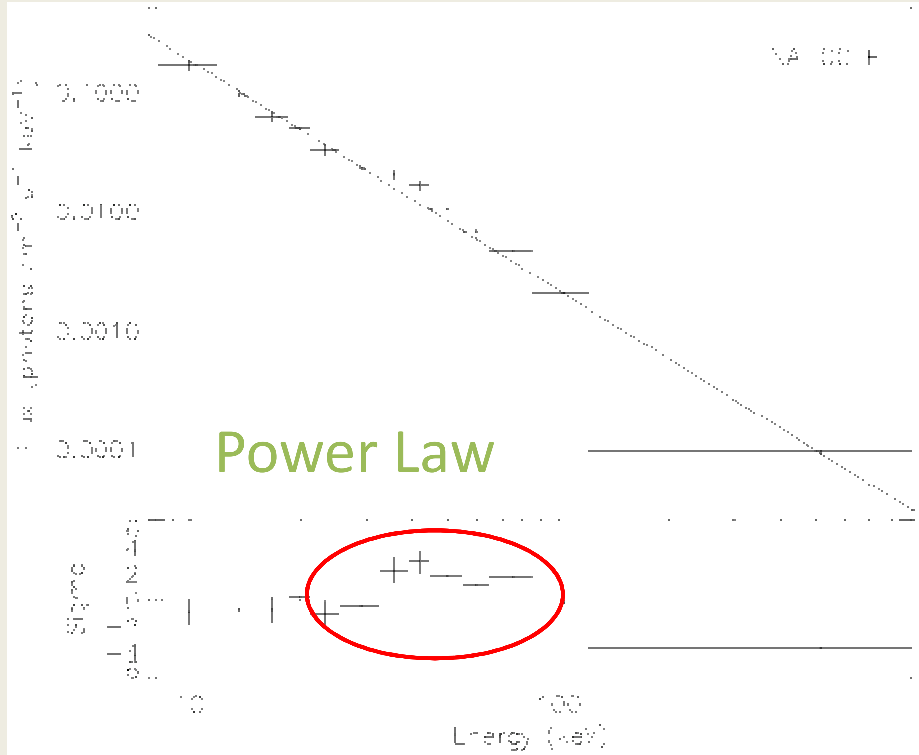


- Correlates with energy
- Peaks in 50 – 74 keV
- Not significant > 110 keV
- Indication of a “dip”

Spectral Analysis

Time Integrated Spectrum [T_0 + 72 – 248 s]





<u>Total Energy</u>

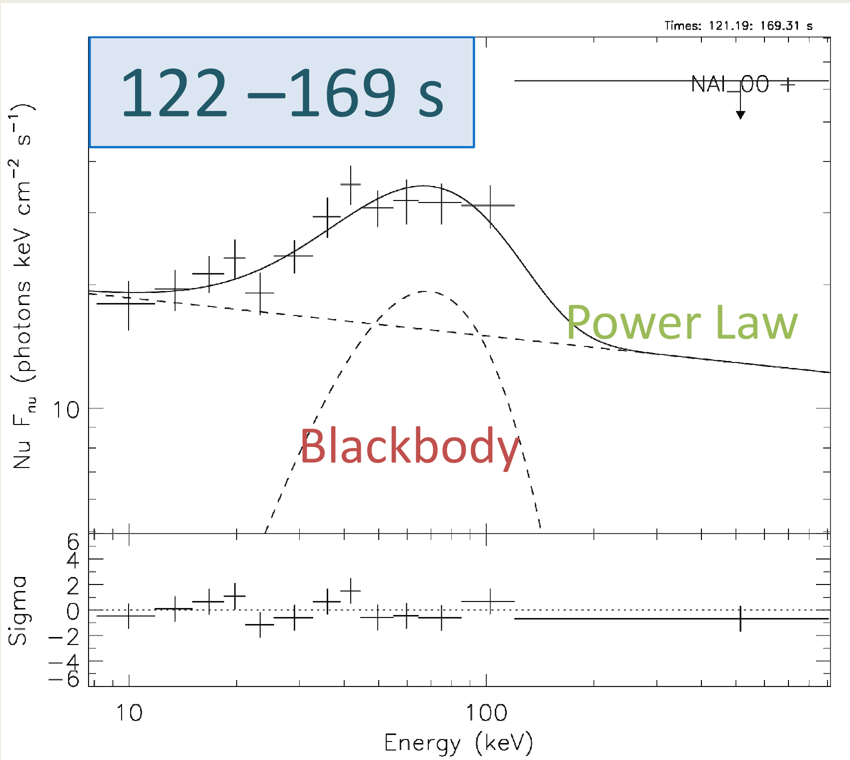
4.3×10^{40} ergs

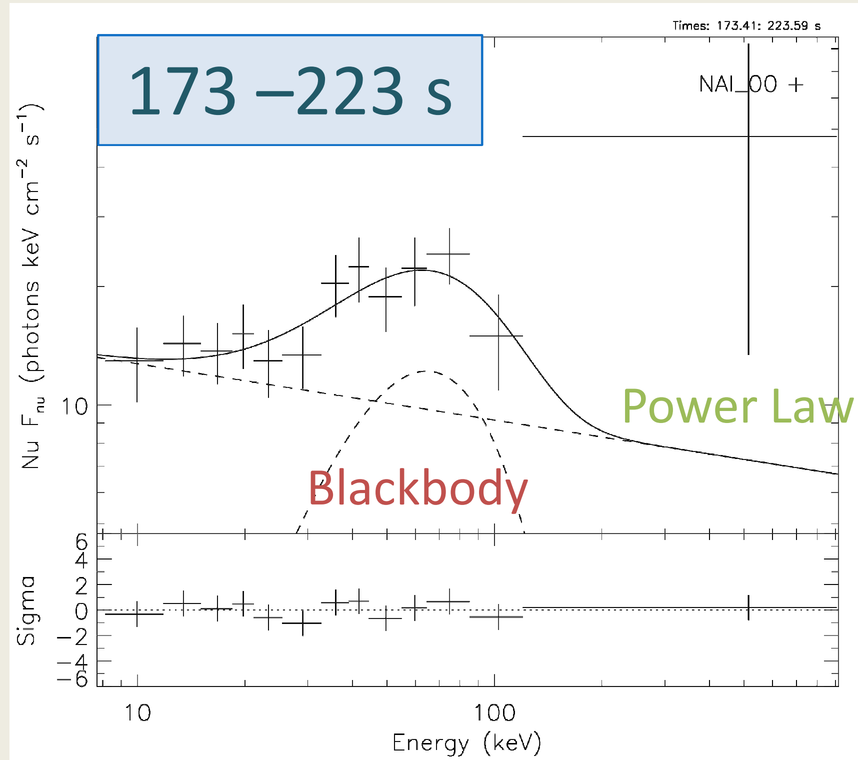
Additional Blackbody (kT = 18 keV) :
ΔCstat = 13.5 (for 2 DOF)

Time Resolved Spectra (νF_ν)

[T_0 + 72 – 117, 122 – 169, 173 – 223 s]

74 – 117 s   Power Law only (Blackbody is not needed)





F_{BB}/F_{TOTAL} = 26%   25%

Evidence of the Blackbody Component

Temporal Properties	**Spectral Properties**
• Pulsations most significant in **120 – 210 s**	• Blackbody required in **122 – 223 s**
• Pulse fraction peaks in **50 – 74 keV**	• Blackbody *kT* ~ 17 keV
• Pulsations not seen above 110 keV	• F_{BB} → 25% F_{PWRL} → 75%

Blackbody: Radius of the Emitting Region

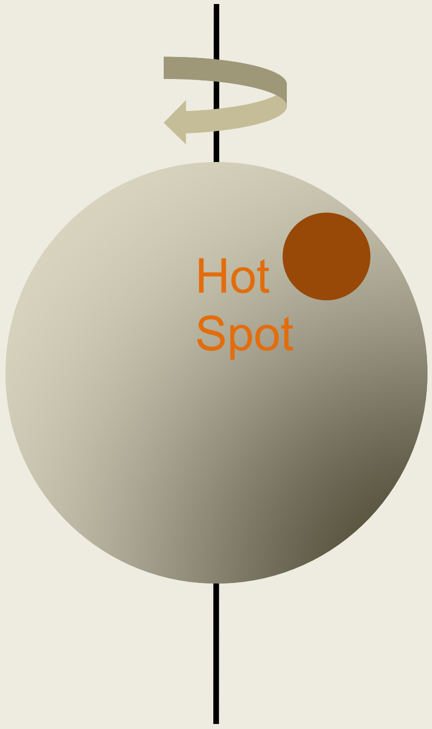
Assuming a hot spot of radius R_{HS} on the neutron star surface

For D = 5 kpc, kT = 17 keV :

$A_{HS} \approx 0.044\ (D/5\ \mathrm{kpc})^2\ \mathrm{km}^2$

→ $\boldsymbol{R_{HS} \approx 120\ \mathrm{m}}$

→ Sign of a trapped fireball



Kaneko et al. 2010

The GBM Magnetar Team

- C. Kouveliotou (NASA/MSFC, USA), G. Younes (USRA, USA), S. Guiriec (UoMD, USA)
- M. Baring (Rice University, USA)
- E. Göğüş, Y. Kaneko, (Sabancı University, Turkey)
- A. Watts, A. van der Horst, D. Huppenkothen, M. van der Klis, R. Wijers, T. van Putten (U. of Amsterdam, The Netherlands)
- O. Kargaltsev (GWU), G. Pavlov (PSU)
- J. Granot (The Open University, Israel)
- J. McEnery, N. Gehrels, A. Harding (NASA/GSFC, USA)
- L. Lin (APC, U of Paris, France)